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Actinide Studies with Ultracold Neutrons

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Effects of Fission on Surrounding Material

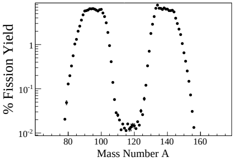
Typically 2 fragments emitted

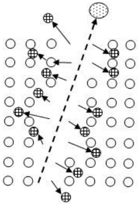
- A$\sim$100, E$\sim$100 MeV, $\frac{v}{c} \sim 10\%$
- Range$\sim$10 μm

Effect on material

- Very energetic, heavy, charged particles
- How is energy deposited in material?
- Damage to the material?
- Near material surface: ejection of matter
- Differentiate between theoretical models

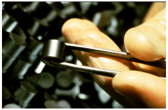
^{235}U fission fragments

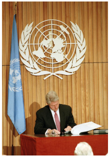




Why study nuclear material aging?

- Nuclear fuels
- Stockpile stewardship
- Lifetime of materials in space





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Inducing Fission with Ultracold Neutrons

Experimental evidence

- Many previous measurements of sputtered atoms per fission
- **Significant disagreement in yield, distribution!**
- Key to differentiating models

New Technique for understanding sputtering

- Induce fission using Ultracold Neutrons
- Excellent control of neutron energy
- Very sensitive probe of fission as function of depth

LANL: Unique Position for work

- LANSCE: one of world's brightest sources of UCN
- Expertise in fabrication and analysis of actinide targets

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Ultracold Neutrons

Class	Energy	Source
Fast	> 1 **MeV**	**Fission reactions / Spallation**
Slow	**eV – keV**	**Moderation**
Thermal	**0.025 ev**	**Thermal equilibrium**
Cold	μ**eV – meV**	**Cold moderation**
Ultracold	$\leq$ **300 neV**	**Downscattering**

How cold is Ultracold?

- Temperature < 4 mK
- Velocity < 8 m/s
- Usain Bolt ~ 12 m/s

UCN can be bottled

- Gravitational $(V = mgh)$: 100 neV / meter
- Magnetic $(V = -\vec{\mu} \cdot \vec{B})$: 60 neV / Tesla
- Material $\left(V = \frac{2\pi\hbar^2 Nb}{m}\right) \begin{cases} {}^{58}\text{Ni}: & 335\text{ neV} \\ \text{DLC}: & 250\text{ neV} \\ \text{BeO}: & 250\text{ neV} \\ \text{Cu}: & 170\text{ neV} \end{cases}$

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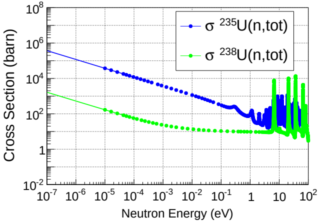
Predictions for UCN-induced Fission in Uranium

Uncharted energy regime

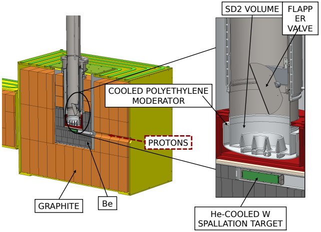
- 3 orders of magnitude lower than ever explored
- Very high theoretical cross section $\sigma \sim \frac{1}{v}$
- 300 neV UCN: 2.16×10^5 barn

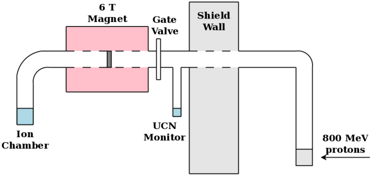


Control depth of fission event

Range of UCN in uranium (μm)						
	DU	NatU	SEU	LEU	HEU	VHEU
$\%^{235}$U	0.2	0.7	2	5	20	100
200 neV	118	66	312	13	4	0.8
300 neV	144	81	38	17	4.5	0.9
400 neV	191	101	45	20	5	1

Ultracold Neutron Facility at LANSCE





UCN Source

- 800 MeV proton beam + W target → spallation neutrons
- single scatter in SD_2: CN→UCN + phonon
- High density at shield wall: 50 UCN/cc
- Pulsed beam: Low background

Experimental Area

- UCN bounce along guides. through Al window, into detection chamber
- 6 T magnet = near 100% polarization

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Fission Rates

Detection chamber

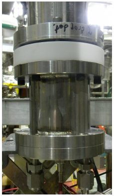
- Cylindrical ion chamber

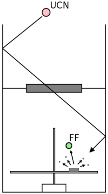
^{238}U

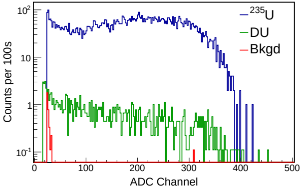
- 2.25 cm diameter, 1 mm thick disk of DU ($\sim 0.2\%$ ^{235}U)
- Rate: $(1.3 \pm 0.8) \times 10^{-4}$ fission/UCN

^{235}U

- 2.2 cm diameter, 1 mm thick disk of HEU ($> 80\%$ ^{235}U)
- Rate: $(1.90 \pm 0.02) \times 10^{-2}$ fission/UCN

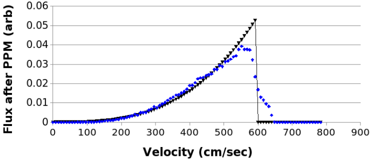






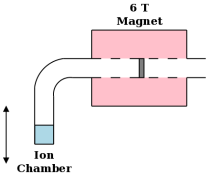
Varying UCN Energy

Simulated UCN energy spectrum after magnet



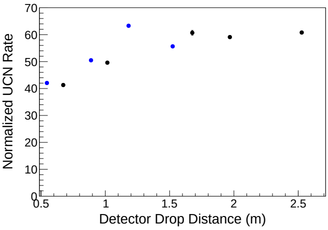
Two primary methods for control

- Magnetic field (60 neV/T)
- Gravity (100 neV/m)



Gravity scan

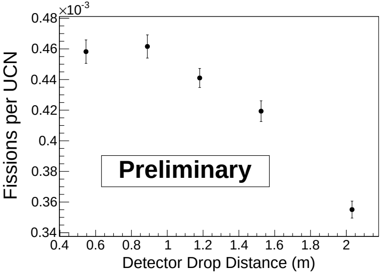
- Adjust height of ion chamber
- Sensitive to geometry, guide quality
- Al window: 50 neV barrier
- $^{3}He + n \rightarrow p + t$



UCN-energy dependence of fission rates

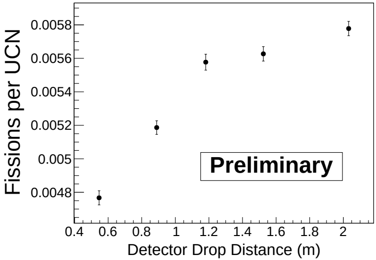
DU sample

- Electropolished, 2.25 cm diameter, 1 mm thick disk
- Measured fission rate decreases with UCN energy



^{235}U sample

- Thin sample: 30 μg heavily oxidized ^{235}U on tape
- Measured fission rate increases as UCN energy increases



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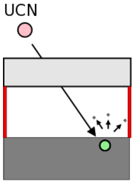
Sputtering from UCN-induced fission

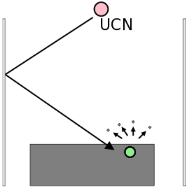
Exposure to Silicon wafer

- 1" diameter, 475 μm thick, polished wafer
- Exposed to 2.2 cm diameter, 1 mm thick electropolished DU disk
- 3×10^7 total UCN in chamber
- 0.18 μg ^{238}U collected on wafer
- Analyze with scanning probe microscopy



Exposure to Ni cylindrical foil

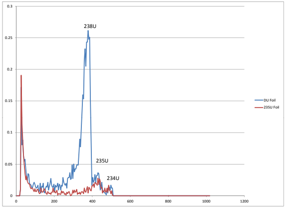
- 0.005" Ni foil, 1.15" diameter, 2.835" height
- UCN bottle: Ni material potential $\sim$ 300 neV
- Exposed to DU disk and 30 μg ^{235}U thin sample



Sputtering on Nickel foil

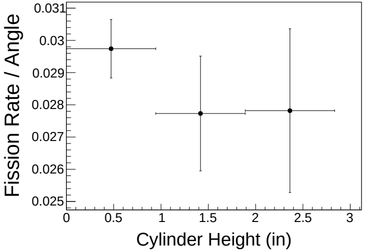
Expose to DU disk and HEU film

- Each sample exposed to $\sim 10^8$ UCN
- Determine yield from α decay rate in ion chamber
- Can distinguish α's from ^{238}U, ^{235}U decay

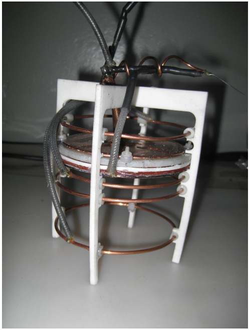


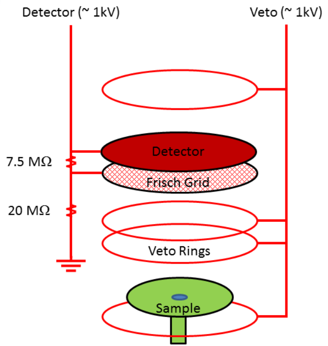
Angular distribution

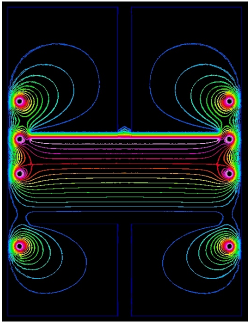
- Mask vertical sections of foil
- Results from DU foil
- Distribution $\sim$ isotropic



Low Background Analysis Chamber







Design Goals

- Amount of sputtered material very low
- Veto signals originating outside region of interest
- Background $<$ 1 count/hour
- Undergraduate Student Project: Jose Ortiz, UW

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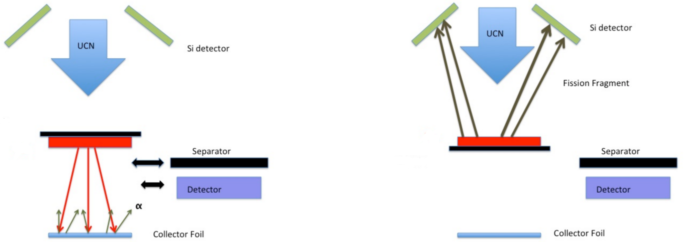
Characterize Ejected Material In-Situ



Key questions:

- How much comes off?
- Size distribution vs. depth/surface quality?
- Kinetics vs. depth?
- Effect of surface preparation?

Summary

First observation of UCN-induced fission

- Previously no fission data at these energies
- Initial characterizations of UCN energy dependence, material thickness

First observation of sputtering from UCN-induced fission

- Proof of principle demonstrated

2014 Accelerator Cycle

- New beamline for parasitic running
- Sample handling to eliminate contamination
- Well-characterized samples of different geometries

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